SOCIETY OF PLASTICS ENGINEERS
Central Ohio Section Extrusion Division

PROFILE EXTRUSION RETEC

February 17 & 18, 1987
Marriott Inn East
Columbus, Ohio

PROFILE EXTRUSION

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The Central Ohio Section, in cooperation with the Extrusion Division of SPE, is pleased to sponsor this conference on **PROFILE EXTRUSION**. To our knowledge this is the first RETEC on this subject.

PROFILE EXTRUSION is at the crossroads of evolving from an artform to a science. The purpose of this conference is to give the attendee an insight into what is developing in the areas of Tool & Die design, process and equipment and materials.

PROFILE EXTRUSIONS are being used in a variety of end products from autobody side moldings to vinyl windows. Anyone involved in the design or manufacturing of profiles should find this conference informative.

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Plastics

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PROFILE DIES AND SIZERS

BY

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INFORMATION NECESSARY FOR DIE DESIGN

Profile extrusion dies as most people know are probably the most complicated extrusion tooling built today. The design of sheet and pipe or tube dies is a science and the results can be very predictable. Irregular shaped profiles can cause many more problems and the design of profile dies is more of an art than a science.

In designing a profile die there are several things that must be known.

First the material to be extruded must be the first consideration. Drawdown and swell can be very different for two different materials. Most producers of PVC in the U.S. recommend a drawdown of 10%, while some polyethylene compounds for profiles have a drawdown of 100%. The manufacturer of the material is the most reliable source to obtain the correct information in designing an extrusion die for a new material.

In requesting the information, the four items we need most are:

(A) Recommended drawndown
(B) Swell of material as it exits die
(C) Recommended die land
(D) Estimated extrusion pressure

TYPE OF DIE

The second item to consider before designing the die is the production requirements of the product. In many instances a simple, inexpensive flat plate die can be used. With some polymers this type of tool will work quite well and give many hours of service producing a good product.

When designing a die for materials that have a tendency to burn or degrade and if the runs are to be long with high volume production, it is more desirable to build a streamlined die. The streamlined die is more costly to build than a flat plate die; however, for long continual runs the payback can be obtained quickly because of less down time for cleanup. Also, the production rates may be higher for streamlined dies for some polymers.

MATERIAL OF CONSTRUCTION

The third item to consider is material of construction. For a non-corrasive polymer with a low extrusion pressure the steel of construction can be a low carbon steel such as 1018 machine steel. If long runs are required it may be desirable to use a stronger material such as 4140 heat treated or a free-machining 420 stainless steel.

When designing a streamlined profile die for PVC, a strong material which can be easily polished is strongly recommended. 4140 meets these requirements; however, it does not have a good resistance to corrosion. The corrosion resistance can be obtained by hard chrome plating the flow surfaces. Chrome plating complicated profile dies is difficult and can be costly.

A better steel for rigid PVC profile dies is 420 stainless steel. It is stress free allowing narrow slots to be wire EDM cut. It can be highly polished. It is easily machined and has a high resistance to corrosion. There are a number of suppliers in the midwest who carry a large inventory of 420 stainless steel.

If you are going to build a complicated die for high volume production, the cost of material is one of the lowest cost items in the die.

The cost of steel for a Main Frame die for a PVC window using 1018 machine steel would be approximately $120. The same die using 420 stainless steel would be approximately $400. If the cost of the die is $10,000, building it of 420 stainless versus 1018 would increase the cost less than 3%.

MACHINE TO BE USED

Another item to consider in the design of rigid PVC dies is the machine it is to be run on. The main consideration here is single screw or twin screw.

For single screw extruders most material manufacturers recommend a die land of 10-1. We have found through experience we are able to obtain better results by using a 15-1 die land. This is for pelletized PVC compound.

If the die is to be used on a twin screw extruder, which is normally a powder compound, we increase the die land to 20-1 and also provide a larger inventory area for material between the end of the screw tips and the start of the transition area.

COMPOUND

The last major item we consider before designing the die is the color of compound to be used. A die that has been properly developed to run white or light colored compound will nearly always run completely different on a very dark or black compound.

Black compound has a tendency to cause more center flow thus resulting in short, thin sections at the outside edges of the part. If the color is known prior to final design of the die, more restrictions can be designed in the center of the die causing the material to flow to the outside.

SHAPE OF DIE

If a small part is to be extruded , a round die works very well and is the easiest to apply heat to. Round heater bands tighten around the circumference of the die allowing for a good transfer of heat. On a large part such as the main frame of a window, it is to the operators advantage many times to have independent heat zones on all four sides of the die. If four are not used, the designer should allow for at least two zones. The top and bottom as one zone and the two sides as the other zone. A few degrees temperature change at the sides of the die versus top and bottom can change the flow enough to keep the product in tolerance. Temperature changes also assist in making small adjustments for slight differences in compound.

A good example of temperature changing the flow of product in a die is on large sheet dies. The thickness of the sheet is monitored automatically and the heat changed at the necessary portion of the die to increase or decrease the thickness of the sheet.

SCREW COOLING

Screw cooling on a single screw extruder can be a tremendous asset in die development and operation of the extruder. Since these machines have a natural tendency to cause centerflow thru the die the centerflow can be retarded by cooling the screw tip.

Best results are obtained by cooling the tip with air. First you must determine the thickness of the metal at the tip of the screw. This thickness must not be greater than 10MM. A thickness over 10MM holds too much heat and the air will not be affective.

When air is forced down a tube in the coredhole of the feed screw, it cools the tip only. If an oil screw cooling unit is used, it cools the tip of the feed screw and as it is traveling back to the temperature control unit, it will heat the feed section of the screw which can be determental to the proper feeding and processing of the material.

SINK LINES

One of the most universal problems in profile extrusion is sink lines.

A sink line is a sink in the material at the intersection of two walls in the profile. Two very similar profiles running on the same compound with the same die design one part will have sink lines and the other will not.

Sink lines may come and go with material changes, temperature changes, and for no apparent reason.

The best method found to reduce sink lines to minimum is to put restrictors at the intersection of two walls. In the die lip keep the two walls seperated, or as a seperate extrusion until just prior to exiting the die lip. A good rule of thumb is to allow the two sections to weld back together for three wall thickness before exiting the die

DUAL DUROMETER EXTRUSION

Dual durometer extrusion is not new to the industry. However, there are more and more people requesting dual durometer dies every day.

The major question asked regarding dual durometer extrusion is "How do I get a good bond of the flexible to the rigid material?" Several thing which can result in a bad bond are:

(A) Wrong heat profile of the flexible material

(B) Moisture in the flexible material can cause poor bonding

(C) It is very important that the two materials will bond together chemically

CAP STOCK EXTRUSION

Capstocking a profile can be as simple or difficult as you wish to make it. Capstock can be applied to the substrate at one of two places in the system.

(A) Between the machine adaptor and the rear of the die.

(B) Just prior to the extrudate exiting the die.

Method (A) works best if the entire part is to be coated with the capstock material or one side only is to be coated such as in vinyl siding.

Method (B) has other advantages. With the proper chanelling, the capstock can be applied only to the portion of the profile that is required. The second advantage to this method is with proper die development the thickness can be controlled very precisely. It is not uncommon to obtain a thickness of 3 to 5 mills on the entire area to be capstocked.

SIZING

Sizing of the profile many times determines the speed of the extrusion line. Many profiles are cooled on air tables. In many instances this is quite adequate for the requirements of many extrusion plants. Many times the only reason a line is not run faster is you cannot hold the proper shape and size of the profile.

With properly designed sizing many materials can be held to the proper shape with a sizer while being cooled in water. Many times the distance between the die and the haul off can be reduced to 3 to 5 meters with water cooling.

Large, complicated hollow parts were typically cooled in water cooled vacuum sizers. It was not uncommon to use three of these units, each having a length of one meter. Today the same part is being cooled using a sizer submerged in a water bath having a total length of .6 to 1 meter long. Best results are obtained by controlling the temperature of the water bath.

STREAMLINED PROFILE EXTRUSION DIES

by
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INTRODUCTION

Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) techniques are being developed for the design of streamlined dies for polymer, metal, and composites extrusion. The software package, STREAM, includes in an expert systems environment, the ability to design dies for solid or hollow, single or multiholed extrudates (1-4). Since either cubic splines or B-splines can be used to fit changing cross-section die surfaces, streamlined surfaces can be designed with smooth exit from and entry into different cross-sections; thereby minimizing rotational motion. Streamlined dies are particularly beneficial for "difficult to extrude" metals, polymers, and composites such as some of the high strength powder metallurgy aluminum alloys and melt transformation extruded polymeric materials. Elimination of rotational flow minimizes surface disruptions thereby improving extrudate quality, enhancing line speed, and decreasing the size reduction of reinforcing substances. This CAD/CAM approach also includes control of the differential volumetric flow to each portion of the extrudate thereby minimizing extrudate distortion.

The capability of converting commercial polymers to high strength extrudates using plasticating extruders and specially designed dies is provided by the melt transformation extrusion (MTE) and coextrusion (MTCE) processes. The MTE process and its refinement by the MTCE process enable the conversion of common polymeric materials such as polyethylene (PE) and polypropylene (PP) to very high strength to weight ratio materials equivalent in properties to those produced by solid state (SSE) and hydrostatic extrusion (HE) of the same material. The advantages of MTE and particularly MTCE over SSE and HE is that the former processes operate at much higher extrusion rates than the latter, and since MTE and MTCE require an order of magnitude lower operating pressure, commercial extruders are used as the melt sources. One patent has already been issued on MTE and another is pending on MTCE.

CAD/CAM STREAMLINED DIE DESIGN

STREAM was developed and first applied to the SSE of metals, and its use demonstrated the advantages of streamlined dies particularly for neat and whisker reinforced "difficult to extrude" aluminum alloys (1-4). Flat entry, conical, and parabolic dies were used prior to the introduction of streamlined surfaced dies. In flat entry dies the extruding material, if it follows the die surface, must make discontinuous changes in direction. In conical dies the material path line is a linear function; and in parabolic dies it is a parabolic or second order function.

It has been demonstrated that the most appropriate constitutive equation for modeling the hot working SSE of powder metallurgy aluminum alloys is a power law model based upon deformation rate and not upon deformation (3,4). Since similar models are quite useful for polymer extrusion, considerable similarity exists and the techniques developed for these metals can be extended to polymeric and composite materials as well. Developing finite element methods (FEM) for predicting the flow behavior and also shear-free streamlines for polymeric materials using an Eulerian grid (fixed in space) also are useful for analysis of the discrete SSE of metallic materials which are traditionally described using a Lagrangian grid system (moves with the material). These FEM techniques being developed at Ohio University include an integration point update (IPU) method using a direct iterative approach to update material properties at the integration points, thereby enabling the analysis of non-linear fluids in complex flow geometries (5,6). Since the material properties are updated at each integration point, the technique will handle fluids that are non-newtonian, viscoelastic, asymmetric, non-isothermal, and transforming.

MELT TRANSFORMATION EXTRUSION

MTE is a continuous process, developed at and patented by Ohio University, that imparts high levels of orientation in one and two directions in polymeric extrudates. Controlled levels of orientation up to nearly complete chain alignment have resulted in strengths of PE and PP comparable to aluminum (7-12). This process has been applied to other materials and should be applicable to many crystallizable polymers in the neat and reinforced states. Using temperature and pressure conditioned polymer melts, orientation is induced in the elongational flow region of specially designed and operated dies on commercial melt extruders. Molecular orientation is retained in the extrudate by crystallization of at least the outer sheath of material inside a constant cross sectional area land of the die, immediately downstream of the shaping section (elongational flow region). Induced orientation and strength are controlled by operating conditions and die geometry. It has been demonstrated that this process produces similar results to those obtained by SSE and HE, even though it is operating at significantly lower pressures. In MTE a melt is oriented whereas the other two processes operate on material in the solid state.

MELT TRANSFORMATION COEXTRUSION

MTCE involves the orientation and crystallization of the core layer of a three layer coextruded ribbon or of a sheath/core fiber prior to exiting from a die similar to the MTE process. However in MTCE the material selected for the skin layers is intentionally chosen to be a substance that does not crystallize prior to exiting from the die thereby causing the skin to act as lubricating layers inside the die. MTCE has been demonstrated using a PP core and a PE skin (13-14). By proper control of temperature gradients in the land of the die, the PP core was crystallized after orientation but before leaving the land of the die. However with proper operating conditions the PE skin layers remained molten inside the die. The skin layers function as lubricating layers and allow the extrusion rate to be limited only by the rate at which the polymer could be supplied to the die from the two extruders. The coextruded ribbons exhibited a high modulus corresponding to the MTE processing conditions. Since the PE skin acted as a crack inhibiting layer the elongation to break of the MTCE extrudates was higher than the typical high strength extrudate from MTE, HE and, SSE processes. The presence of this unoriented skin layer on the coextruded products and its effect on subsequent properties such as crack inhibition, diffusion, and adhesion should be useful in many applications.

PROFILE EXTRUSION OF POLYMERS

STREAM is being modified to handle fiber spinning and coating multiple hole spinnerets and profile extrusion of neat and reinforced polymeric materials. The initiation of instabilities that limit fiber spinning rates should be suppressed by the use of streamlined flow. In profile extrusion improved flow to thin sections and better dimensional control should be possible.

During conventional melt extrusion of complex shapes it is often difficult to supply appropriate amounts of material to each part of the extrudate. This results in either immediate shape loss or the development of asymmetric residual stress distributions that cause time dependent shape changes. Similar difficulties arise when a significant velocity component occurs perpendicular to the extrusion direction. Such velocity components can exist due to the absence of smooth exit from converging sections in the die and also from the release, upon exiting, of elastic energy stored during non-smooth entry into converging sections or developed as a result of the flow pattern. Profile extrusion of polymers reinforced with glass fibers and other agents is also susceptible to excessive breakage of the reinforcement if significant rotational flow occurs within the die.

The purpose of streamlining the flow of material in converging sections of dies is to minimize the transverse components of the discharge velocity, supply material equally to each differential section of the die discharge, and to eliminate the macroscopic rotational flow regions. Significant transverse velocity components and improper differential flow rates lead to loss of extrudate dimensional control and excessive residual stress, whereas macroscopic rotational flow regions can contribute to extrudate defects. The use of a single cubic spline for each streamline to define the entrance to and exit from a converging flow region will lessen the transverse velocity components. To achieve the desired differential flow rates, it is necessary to employ a program such as STREAM. If the assumption that the fluid will follow the contours of the die is valid, i.e. conform to forced streamlines, cubic spline fits and proper attention to the differential flow rates may be sufficient. However, if the material due to its non-newtonian and viscoelastic character defines, as many polymeric materials do, its own streamlines, then disruptive rotational flow regions might still occur even with cubic spline die surfaces.

Lack of confirmation to the wall geometry in ten to twenty degree converging angle dies appeared to have occurred in MTCE runs that were intentionally interrupted by rapid cooling of the die, and the solidified polymer extracted from the die (13). Apparently the streamlines defined by polymeric fluids can continue to deviate from the die wall even when the entry angle of the die approximates the streamlines occurring for the same fluid in a flat entry die (15-17). Therefore, the non-newtonian and viscoelastic character of the fluids should be characterized to calculate the differential flow rates in regions of differing stress fields and to predict the complex sculptured surfaces to which the fluid may more closely conform.

It may be necessary to predict the streamline shape that the fluid would describe if it were to change its shape in a shear free environment, i.e. without the influence of constraining walls, and then to machine the dies to that shape. Designing and then machining the die shape to shear free flow streamlines should also tend to minimize the shearing component of the flow. However, since the shearing flow near the wall in all but the land section would probably not by confined to the skin layer, shear free streamlined shaped dies may not represent the optimum shape.

The B-spline approach is more flexible than the cubic spline approach discussed earlier. B-splines are parametric polynomials particularly well suited to computer techniques for accurately fitting complex shapes. Although the cubic spline approach has been shown to be an improvement over other approaches for SSE of metals, the die surfaces are probably not actual streamlines for all types of flowing materials, particularly not for polymers. The improvements noted for cubic spline converging sections are apparently due to the smooth entry and exit that result from setting zero longitudinal velocity gradients at the entry and exit. This choice of boundary conditions for the cubic spline approach along with the entry and exit velocities define the normalized shape of the surface (i.e. if made dimensionless by use of an appropriate length).

CONCLUSIONS

The streamlined die approach has been used successfully for "difficult to extrude" aluminum alloys demonstrating the capability of producing good extrudates with complex cross-sections, whereas distorted extrudates resulted when other dies were used. Stream is being modified to handle multiple hole spinnerets and profile extrusion of neat and reinforced polymeric materials. The initiation of instabilities that limit fiber spinning rates should be suppressed by the use of streamlined flow. In profile extrusion improved flow to thin sections and better dimensional control should be possible.

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